temperature ranges. These differences result from the temperature non-linearity of the thermal reactor.

[0087] By using Equation (54), some uncertain factors caused by the system non-linearity and disturbances are limited in the MBPC control loop, which ensures that the MBPC can always generate the reasonable control setpoints for the inner PID control loop, enhances the stability, control margins and robustness of the hybrid cascade MBPC control system.

7. PID design

[0088] The PID loop is an inner control loop that works in concert with the outer MBPC control loop. Tuning parameters (e.g., control gains) of the PID controller are based on the accumulated control experiences and the open-loop identification analysis of the vertical thermal reactor. The PID controller is used for both modeling (FIG. 8) and normal control (FIG. 6, 18, 19). Its structure is shown in FIG. 13. The PID algorithm is mathematically represented by:

CJB
31 MARCH
2005

$$\begin{aligned} Pw(t) &= \frac{1}{\delta}\{\ E_s(t) + Iout(t) + Dout(t)\ \}\times G \\ &= \frac{1}{\delta}\{\ E_s(t) + \frac{T_s}{T_i}\sum_{j=0}^{t}[\ E_s(t) + \frac{T_d}{T_s}D_s(t)\ ]_j + \frac{T_d}{T_s}D_s(t)\ \}\times G \\ &= k_p(t)\{\ E_s(t) + k_i(t)\sum_{j=0}^{t}[\ E_s(t) + k_d(t)\,D_s(t)\ ]_j + k_d(t)\,D_s(t)\ \}\times G \end{aligned}$$

(55)